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Effects of mental rotation, visual aids and training on inspection performance during airport baggage inspection

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EFFECTS OF MENTAL ROTATION, VISUAL AIDS AND TRAINING ON INSPECTION PERFORMANCE DURING AIRPORT BAGGAGE INSPECTION

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ABSTRACT

Since 9/11, airport security has become an area of critical national security. The current study investigates the effect of mental rotation training and the presence of visual decision aids on inspection performance. Forty-eight participants were divided into two groups (Group A and Group B) of twenty-four each. Each group was provided with training on visual inspection, baggage screening and on using the software simulation of airport baggage inspection. Participants had to identify from images any object that cannot be allowed on a passenger plane and register a response by clicking one of the buttons, "Threat" or "No Threat". Participants in Group A were provided with visual decision making aids whereas participants in Group B were provided with none. Upon the completion of the first set of trials, all the participants underwent an advanced training session on mental rotation. The participants then repeated the same experiment as before. There was a significant interaction effect between training and rotation for response time, $F(1, 184) = 8.59$, $p = .0038$. Individuals that received no training and had rotated objects performed the worse compared to all other conditions. Response times for images with visual aids improves significantly ($F(1, 184) = 20.74$, $p =0.0001$) lower ($M = 3.70$ seconds, $SD = 0.50$) when compared to the response times for images after without visual aids ($M = 4.03$ seconds, $SD = 0.53$). Accuracy for images without training was significantly ($F(1, 184) = 34.23$, $p < 0.0001$) lower ($M = 74.73$, SD = 10.92) than the accuracy for images after training ($M = 83.42$, SD = 10.51). Accuracy for images presented without visual aids was significantly ($F(1, 184) = 19.58$, $p < 0.0001$) lower ($M = 75.86$, SD = 11.69) than the accuracy for images presented with visual aids ($M = 82.29$, SD = 10.51). The results from the experiment show that mental rotation has an effect on inspection performance of an airport baggage inspector and that the

performance can be improved by training the inspector in mental rotation. It was also observed that providing visual decision making aids can improve the inspection performance.

CHAPTER 1. INTRODUCTION

Millions of people fly everyday. Most of them are law-abiding people who have no intention of harming anyone. But there is always the possibility of a terrorist or a criminal hiding among them. Also many people without any intention to harm anyone may carry hazardous materials onto the plane. Airport security plays a major role in avoiding these problems.

Airport security tries to cutoff the possibility of passengers carrying any material that may be used for destructive purposes on the plane. The Transportation Security Administration (TSA) plays an important role in Setting up standards for this process. TSA has made a list of all items that are allowed on the plane (TSA, 2003 Appendix A). The airport security officials go through the luggage of each person to find out if they are carrying any prohibited items.

This search process is done by more than one method. One method is to open up the baggage of each and every person. Another method is to pass the baggage through an x-ray scanner to see what is in the baggage. Airport baggage inspection can be considered similar to the industrial quality control inspection. So, many of the aspects of quality control inspection are valid in case of the airport baggage inspection. Thus the successful detection of threats depends on the ability of a person to detect the object and the ability to distinguish it as a threat.

From the literature, it can be found that some of the factors affecting the detection capabilities of an inspector can be classified as:

Environmental

- Auditory Noise (Taylor et al, 2003)
- Visual noise (or presence of distracters) (Kawahara, 2003)
- Speed of inspection (Wickens, 1984)
- Training etc (Weiner, 1975).

Descriptive

- Eye movements and fixations (Khasawneh et al., 2003)

There are some cognitive factors that can affect the inspection processes like mental rotation ability and the ability to join different objects virtually to see if they form anything dangerous. In addition, the ability to interact efficiently with the x-ray inspection systems can have an impact on performance.

After the incident of September 11, 2001, many agencies have been working towards developing more sophisticated inspection systems and many organizations are also working towards developing better procedures to improve the human performance in these inspection tasks. Regardless of the sophistication achieved through technology, it is the performance of the human operator that ultimately matters, as the final decision has to be made by the person inspecting the objects.

CHAPTER 2. LITERATURE REVIEW

2.1 Introduction to Airport Baggage Inspection

The most common protection against terrorism at airports is screening the passengers and their baggage. There have been technological developments in security systems. All or most of them are monitored, interpreted and controlled by human operators. So it is the performance of a human operator that determines the effectiveness of detecting and preventing the threats at the airport in conjunction with the technology. It has been possible to achieve significant performance improvements by systematically assessing the impact of different factors that can affect human performance (Ainsworth, 2003). Ainsworth states that, currently training on visual strategies is being given to airport officials to improve the performance. There are many other features of task and interface design that can improve an operator's perception and recognition of potentially suspect item. Today, there is no comprehensive body of knowledge in the field of ergonomic for design of security tasks (Ainsworth, 2003).

Table 1 shows the typical errors and the reasons for the errors in a checking task using the x-ray aided visual examination (Ainsworth, 2003).

The most modern x-ray inspection systems present a colored image to the checker and permit the movement of item, or its image on the VDU screen to be halted for more detailed examination. However it must be stressed that even where the observer has direct control over the inspection rate, there is implicit external pacing due to passenger flow which is between six to ten seconds (Gale et al., 2000).

X-ray baggage inspection shares many of the characteristics of industrial visual inspection. It also shares some characteristics with medical x-ray examination (Gale et al., 2000).

All the above cases involve a visual search for particular target items that must be classified as being either acceptable or needing further investigation.

Table 1: List of Typical Errors Made and Their Reasons (Ainsworth, 2003).

	Type of errors	Potential reasons
1	Baggage is presented for viewing but security official decides not to observe it.	Competing and more attractive attentional cues from nearby
		Prolonged time in task
		Fatigue or eyestrain
		Workplace layout
		Low expectation of finding dangerous items
		Low motivation
2	Security official fails to perceive any potentially dangerous items when these are presented in the baggage	Insufficient time for search
		Movement speed too fast
		Poor search strategies
		Inadequate display conditions
3	A potentially dangerous item is perceived but the security official incorrectly decides that it is acceptable	Unclear or variable standards
		Lack of time
		False alarms are penalized or are perceived as being, especially because of the possible reactions of the passengers
		Rejection involves more effect
4	Security official locates a dangerous item but this is then not identified during unpacking	Personnel who are responsible for unpacking the baggage are unaware of the reasons for security checkers suspicions

Thus following are some psychological issues that must be considered (Gale et al., 2000).

1. The perpetual cues must be made as prominent as possible, so that targets stand out clearly. These aspects can be measured using the Signal Detection Theory in terms of the detectability of the targets.

2. When the security official looks at an item on the baggage inspection screen and is unsure about it, then the inspector needs to make a cautious decision and select the baggage for manual search.
3. After undertaking any visual monitoring task for even a limited time, the observer's vigilance starts to decline and the performance is degraded.
4. There are presumably a relatively small number of potentially dangerous items, thus the bulk of the feedback that the security official receives is from the false alarms, which will tend to make them adopt less cautious criteria.

2.2 Inspection Aspects and Different Factors Affecting Inspection Performance

2.2.1 Introduction to Visual Inspection

Airport baggage inspection can be considered very similar to the industrial quality control inspection or a medical x-ray inspection. The main difference between the industrial quality control and the airport baggage inspection is that the system inspected is sentient in the latter case (Thompson, 2003). In homeland security, the terrorists are intelligent agents who will attempt to use information about inspection protocols to lessen the discovery of both the terrorists and their baggage. Moreover, detecting explosives is more difficult than detecting weapons because they are non-metallic and do not appear in any predictable shape (Ellenbogen, 1996).

Visual search requires a series of short fixations by the eye during which information is gathered. These fixations are interspersed by rapid eye movements in which the area of fixation is moved to another part of the object being viewed. The area that surrounds the fixation point, and from which the eye collects information, is called the visual lobe. (This visual lobe is elliptical but is treated as a circle for convenience). The boundary is defined by the angle from the center of fixation, which allows a 50 percent detection rate. The size of the target being searched for, the level of contrast, and the luminance level of the background all directly affect the detection rate of a target (Drury, 1994). Moreover, if the prior expectation of a target occurring is increased, the probability of detection also increases (Drury & Addison, 1973).

Visual inspection as a process task can be defined as the aided or unaided observation of details, without measurement. Visual search and decision-making are recognized as the two most important components of the inspection task and the two determinants of inspection performance (Splitz & Drury, 1978). Megaw & Richardson's model suggests that there are four separate stages: (Megaw & Richardson, 1979)

- Search - involves scanning item with the aid of head, eye and hand movements (in cases where the objects have to be moved).
- Detection - involves identifying that the item is different from its ideal state.
- Judgment - involves deciding whether the difference constitutes a fault according to the standards to which the task is being performed.
- Output decision - involves making decisions whether to accept or reject and take the appropriate action.

From the above two models (Drury's model and Megsaw's model), it can be said that they both do not differ much. It can be observed that the model proposed by Megsaw divides search into search and detect and decision making into judgment and output decision.

2.2.2 Effects of Auditory Noise

There are many aspects affecting the inspection performance of the inspectors. One of them is the effect of intermittent, random and continuous auditory noise. Taylor et al., (2003) showed that the random and intermittent noise patterns have a deteriorating effect on the accuracy of the inspectors performing an easy search task and none of the noise patterns had any effect on difficult search task. The difficulty level of the inspection depends on whether the inspector is looking for several items at a time or doing a very fast search or doing an inaccurate search.

2.2.3 Effects of Eye Movements

Another aspect affecting the inspection performance is an individual's eye movements. Megaw & Richardson (1979) studied the effects of eye movements during industrial and medical x-ray inspection and have shown that:

- Inspection time differences reflect the number of fixations needed to search for and find a fault rather than differences in time of each fixation
- Fixation times are short in tasks without clear fixation points.
- In the objects which are manipulated, scan paths are fixed and errors occurred as a result of sticking to these scan paths
- Peripheral vision is used for scanning moving objects which subtend a large visual angle

It has also been found that the area covered during an inspection did not have any affect on the overall performance (Khasawneh et al., 2003).

It has been observed that the visual inspection consists of a series of eye fixations followed by saccades or brief eye movements from one fixation point to the other. Studies suggest that eye movement scanning strategies, pattern of fixations and saccades over the inspection area can be altered and improved (Wang et al., 1997; Gramopadhye et al., 1997; Kundel et al., 1990). Eye movement behavior can be classified into two categories: random and systematic. Random behavior assumes memory-less search i.e., any particular fixation area is as likely to be viewed as any other, regardless of how many times it has already been viewed. Systematic behavior assumes perfect memory where each fixation will be viewed only once per scan of a search area. True human search patterns lie somewhere between random and systematic behavior (Morawski et al., 1980). Arani et al (1984) showed that systematic eye movement behavior results in better inspection performance. So efforts to make the inspectors follow systematic search pattern can significantly improve inspection performance.

2.2.4 Effects of Speed of Inspection

Another aspect is the speed of inspection. The speed of inspection is affected by the following four factors (Wickens, 1984):

- Number of elements to be searched: As the number of elements goes up, the time for search also increases
- Search rate increases as the total amount of information in the display increases
- Searching for one of several targets is slower than searching for one
- Number of different stimulus dimensions that can be used to define a target does not affect speed if they are redundant

In the case of baggage inspection, an inspector has to search for one or more target items, which means that the time required to inspect a baggage is relatively high. Gale et al., (2000) observed that the pacing of the detection task in case of baggage inspection is controlled to a large extent by the passenger flow and this pace is generally between 6 and 10 seconds. Since the time for inspecting a bag is restricted, it can be inferred that the overall accuracy may be affected.

2.2.5 <u>Effects of Training</u>

Training is another factor affecting inspection performance. Training can significantly improve inspection performance. Training has shown a powerful effect on inspection performance (Wiener, 1975; Drury & Gramopadhye, 1990) when applied to both novice and experienced inspectors. There have been some experiments to demonstrate the methods of successful training (Gramopadhye et al., 1997). Some of the methods identified for training are:

- Active training: this is where the participant is made to physically respond rather than listening and observing passively (Czaja & Drury, 1981).
- Knowledge of results (Kleiner & Drury, 1993)

A study showed that search behavior affects inspection performance and this can be improved by training (Wang et al., 1997). Practice has also been examined as one of the factors improving the inspection performance (Bloomfield, 1975).

2.2.6 <u>Visual Aids</u>

Several investigations have focused on improving the reliability of visual inspection methods through the provision of visual aids (Bailey, 1984; Rojahn & Schulze, 1985). Job aids or inspection aids are useful in improving the visual search. Job aids like the eye position feedback for inspection of radiographs significantly improved the accuracy (Kundel et al., 1990).

2.3 Mental Rotation

An important factor that may affect the inspection performance is mental rotation. This is because the target objects (especially the ones in the case of baggage inspection) can be aligned in many ways. Mental rotation is the ability to rotate mental representations of two and three-dimensional objects. Several researchers have conducted experiments to understand the concept of mental rotation and to develop experimental procedures to identify the mental rotation abilities (Shepard, 1971 & 1988; Cooper & Podgorny, 1976; Robertson & Palmer, 1983; Paquet, 1991; Schacter, Cooper & Delaney, 1990). Shepard (1971) conducted the very first experiment wherein he presented pairs of two-dimensional representations of three- dimensional objects to his participants and the participants had to decide if the two figures could be brought into congruence by mental rotation. The main result of this experiment was the discovery that there is a linear relation between the response time of the participants and the angular difference between the two objects. Mental imagery also resembles perception, in the sense that information about the special relations is preserved within the representations (Kosslyn, 1981). Image rotation can be understood in this context as a series of transformations of mental iconic representations. However, it is unclear whether mental transformations are holistic or piecemeal. A holistic process is where the participant rotates the representations as a whole where as a piecemeal process is where the participant splits a complex representation into smaller pieces or features and rotates them individually. Bethell-Fox and Shepard (1988) suggested that mental rotation could be either a piecemeal or holistic process. They suggested that greater familiarity with the stimuli would change the rotation process from a piecemeal to a holistic process. Cooper & Podgorny (1976) concluded that the processes underlying mental rotation is holistic in nature. Another approach used to investigate the nature of visual mental rotation is the use of hierarchically structured stimuli of large letters composed of smaller letters (Robertson & Palmer, 1983). Large letters were constructed from spatial arrangements of small letters (Figure 1). Robertson & Palmer (1983) found an advantage when the task was based on large letters and concluded that the rotation is holistic.

```
FFFFFFF      RRRRRRR
F            R
F            R
FFFFF        RRRRR
F            R
F            R
F            R
```

Figure 1: Example of large letters composed of smaller letters (Robertson & Palmer, 1983)

Paquet (1991) using a similar task and stimuli, showed that the data could be equally explained as a piecemeal process. Another approach for exploring the nature of image rotation is to compare the rotation slopes of possible and impossible objects (Dror, Ivey & Rogus, 1997). Both possible objects and impossible objects can be easily encoded by their parts and how they are organized. While the possible shapes can be easily encoded as a global image, it is more difficult to encode impossible objects in such a way.

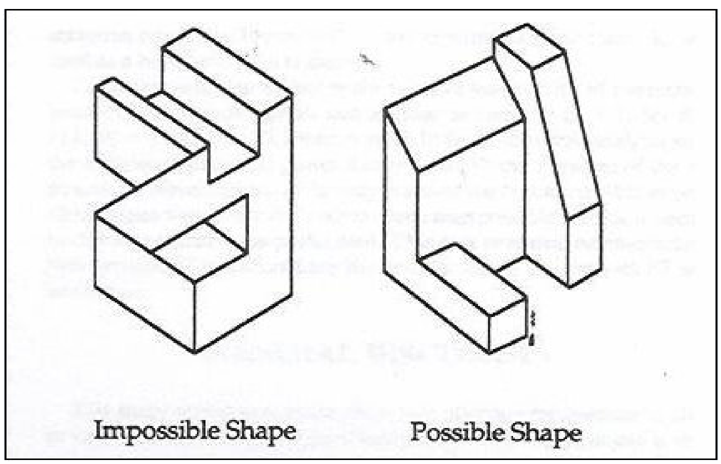


Figure 2: Difference between possible and impossible objects (Dror, Ivey & Rogus, 1997)

Impossible objects are more difficult to process and process holistically than are possible objects (Schacter, Cooper & Delaney, 1990). Dror et al., (1997) reasoned, therefore, that impossible objects are easier to transform in piecemeal than in a holistic one.

Past research has shown that error rates reflect rotation in a comparable way to response times and are to some extent interchangeable (Salthouse, 1992). Cooper & Podgorny (1976) suggested that two factors contribute to response times during mental rotation. First, response times increase with greater angular distance through which the representation needs to be rotated. This will be found in both holistic and piecemeal representations. Second, response times increase with the greater number of segments that need to be processed. In a holistic representation, only one segment is processed, whereas in a piecemeal representation, more segments are processed, and the number of segments in a piecemeal representation increases with greater complexity of the object.

The index most often used to measure mental rotation is the slope of regressed reaction times. This index measures the time taken to make judgments of whether presented pairs of figures are the same or different, as a function of angular disparities between the identical pairs of figures. If the reaction times for judgments monotonously increase as the disparities increase from 0 to 180 degrees, or inversely from 0 to 180 degrees then it is assumed that mental rotation occurs. This function is called the angular disparity effect.

A few experiments were done to examine the effect of problem solving strategies on mental rotation. Shepard (1988) reported that the overall mean reaction time for the mirror images was 3.8 seconds. This was one second more than the congruent pairs. Johnson (1990) concluded that these results may be linked to the problem solving strategy of the participants. According to him, one of the problem solving strategies that may be considered in mental rotation task is that 'if two pairs of figures are not identical, then they can be mirror images'. So it takes more time to find if the objects are identical and then check if they are mirror images.

It is also argued that the degree of familiarity also has an affect on mental rotation. The identification of alphabets and naming of well known objects produced slopes that were almost flat (Corballis & Nagourney, 1978) whereas the slopes for discrimination of Shepard's type figures and random polygons were very large as compared to the latter case (Folk & Luce,1987).

Some research was also done to determine if the figural complexity influences the mental rotation rate. There has been a lot of controversy to whether figural complexity had any affect on mental rotation. Metzler (1974), Yuille (1982) and Barfiel et al., (1988) reported that there is a decrease in the mental rotation rate with the increase in figural complexity. These results are in contrast with the results from Cooper (1975) and Folk & Luce (1987). This might be because of the fact that the experiments done by Metzler and Yuille were performed with two-dimensional representations of three-dimensional objects whereas the experiments done by Cooper and Folk were performed using two-dimensional figures. Bryden (1990) used three-dimensional objects in his experiment but his results did not replicate the findings from Metzler (1974) and Yuille (1982). Cooper & Podgorny (1976) argued that if an image is transformed holistically, the entire image would be rotated as a single unit, and, therefore, the complexity of the image should not affect the rate of this logic. They used polygons of varying complexity to find that the rate of rotation was not affected by the complexity of the stimuli. Smith & Dror (2001) showed that when images were meaningful, there was an interaction between angle of rotation and complexity but when the objects were meaningless, there was no interaction.

2.4 Signal Detection Theory

An important theory to take into consideration in the case of the inspection task is "signal detection theory". Initially, signal detection theory was developed to overcome the problem of guessing by the participants (Green & Swets, 1966). Signal detection theory approaches the participant's behavior in detecting a threshold as a form of decision-making. In each trial of a signal detection test, two sets of two possibilities are possible: the sensory stimulus can be presented or withheld, and the participant can report perceiving the stimulus or not. If a stimulus is presented and the participant says yes, the trial is a "hit." If no stimulus is presented but the participant still says yes, it is a "false alarm" and might indicate that the participant is motivated to guess. If a stimulus is presented and the participant says no, it is a "miss". Finally, if no stimulus is presented and the participant says no, it is a correct rejection. Signal detection theory states that nearly all reasoning and decision-making takes place in presence of some uncertainty. Signal detection theory provides a precise language and graphic for analyzing decision making in the presence of uncertainty.

CHAPTER 3. MODEL AND HYPOTHESES

3.1 Problem Description

It can be observed from the literature that mental rotation surely has an affect on the person's ability to identify and distinguish things. It can also be inferred that training and visual aids also improve the inspection performance. In the case of airport baggage inspection, threat objects appear to the inspector in all positions and angles. Most of the baggage inspection time goes towards identifying an object and making a decision as whether the bag should be allowed to pass. The main aim of this experiment is to find whether the provision of visual aids and mental rotation training have any effect on the accuracy and speed of visual inspection.

3.2 Model Description

Visual inspection is affected by many factors. Visual inspection involves visual search and decision-making. Megaw & Richardson (1979) showed that eye movements and fixations have an effect on the visual search aspect. Visual search is also influenced by the speed of inspection (Wickens, 1984). It has been argued that mental rotation may affect inspection performance. Many experiments were conducted to demonstrate that the response times increase in case of rotated objects (Shepard, 1971 & 1988; Cooper & Podgorny, 1976; Robertson & Palmer, 1983; Paquet, 1991; Schacter, Cooper & Delaney, 1990). Degree of familiarity of the object has an effect on the mental rotation ability (Corballis & Nagourney, 1978). It has also been showed that training has a powerful effect in improving the inspection performance (Wiener, 1975 & Gramopadhye, 1990). It has been found that the provision of visual aids and job aids, which help in decision making, can also improve visual inspection (Bailey, 1984; Rojahn & Schulze, 1985, Kundel et al., 1990). From the above discussion, it is argued that mental rotation and visual search patterns or eye movements have an effect on the visual inspection. The visual inspection performance (time and accuracy of inspection) can be improved by training for mental rotation and eye movements. It can also be argued that by providing visual aids and job aids, the inspection performance can be improved. Based on this argument are the following hypotheses.

3.3 Hypotheses

3.3.1 <u>Hypothesis 1</u>

"Inspection time will differ for objects that require mental rotation as compared to objects that do not require mental rotation".

An experiment conducted by Shepard (1971) showed that there is a linear relation between response time and angular difference between two objects, one of which requires mental rotation and the other does not. Salthouse (1992) showed that error rates reflect rotation in comparable way to response times and are to some extent interchangeable. Cooper & Podgorny (1976) suggested that response times during mental rotation increase with greater angular distance through which the representation needs to be rotated.

3.3.2 <u>Hypothesis 2</u>

"Inspection performance (e.g. accuracy and time) will improve for inspectors that receive mental rotation training".

It has been argued that the degree of familiarity has an effect on mental rotation. The identification of alphabets and naming of well known objects produces slopes that were almost flat (Corballis & Nagourney, 1978) whereas slopes for discrimination of shepard's type figures and random polygons were large as compared to latter case (Folk & Luce, 1987). It has been shown that training has powerful effect on inspection performance (Wiener, 1957). Practice has also been examined as one of the factors improving the inspection performance (Bloomfield, 1975). So this hypothesis is based on the above arguments that mental rotation training, familiarity of the objects searched and practice would improve the performance levels.

3.3.3 Hypothesis 3

"Inspection performance (e.g. accuracy and time) will differ for inspection with visual aids as compared to inspection without visual aids."

Several investigations have focused on improving the reliability of visual inspection methods through the provision of visual aids (Bailey, 1984; Rojahn & Schulze, 1985). Job aids or inspection aids are useful in improving the visual search. Job aids like the eye position feedback for inspection of radiographs significantly improved the accuracy (Kundel et al., 1990).

The following figure shows a graphical representation of the elements expected to affect inspection performance and the proposed hypotheses.

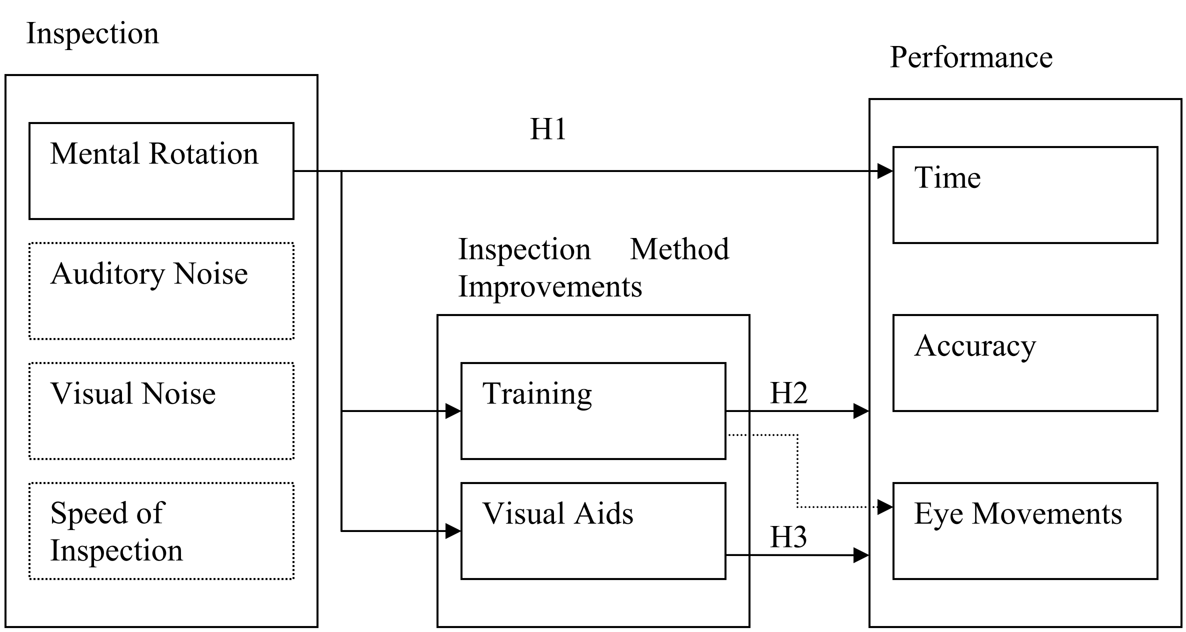


Figure 3: Conceptual Model

CHAPTER 4. METHOD

4.1 Experimental Design and Layout

To test the hypotheses, a 3x2 AOVA model was used with visual aids, training, and rotation as the independent variables with two levels each.

4.2 Participants

The participants consisted of the faculty, graduate and undergraduate student population of the Louisiana State University. Forty-eight participants (40-male, 8-female) were selected. After the selection of participants, they were given a demographic questionnaire that included questions related to the participants experience in the industrial quality control inspection or airport baggage inspection. The participants with some kind of experience in these fields were eliminated.

4.3 Equipment and Material

The apparatus consisted of a computer simulated airport baggage inspection system. This was achieved by presenting the participants with a series of x-ray images on the computer screen. These images were similar to the ones on the x-ray baggage screening machine. These images were paced eight seconds per image. This pace was derived from an observation by Gale et al., (2000) which suggested that there was an implicit external pacing for inspection due to passenger flow which was between six to ten seconds per item. A program was developed in Microsoft VisualBasic.NET® 2003 to record the responses. When a participant identifies the target object, he or she would respond by clicking there is a threat. Then the screen would be presented for the participant to identify the type of object. The buttons on this screen were labeled with the name of the threat object as indicated in the TSA permitted/prohibited list (appendix A). If the participant thought that there was no threat object in the image, they then could make such a response by clicking on the button at the bottom of the screen which says “No Threat”. Response time was captured from the time the image was presented until the participant indicated “Threat” or “No Threat”. Accuracies were noted based on the user’s response. For the part of the experiment where visual aid was provided, a visual image was displayed at the top left corner of the screen along with the description.

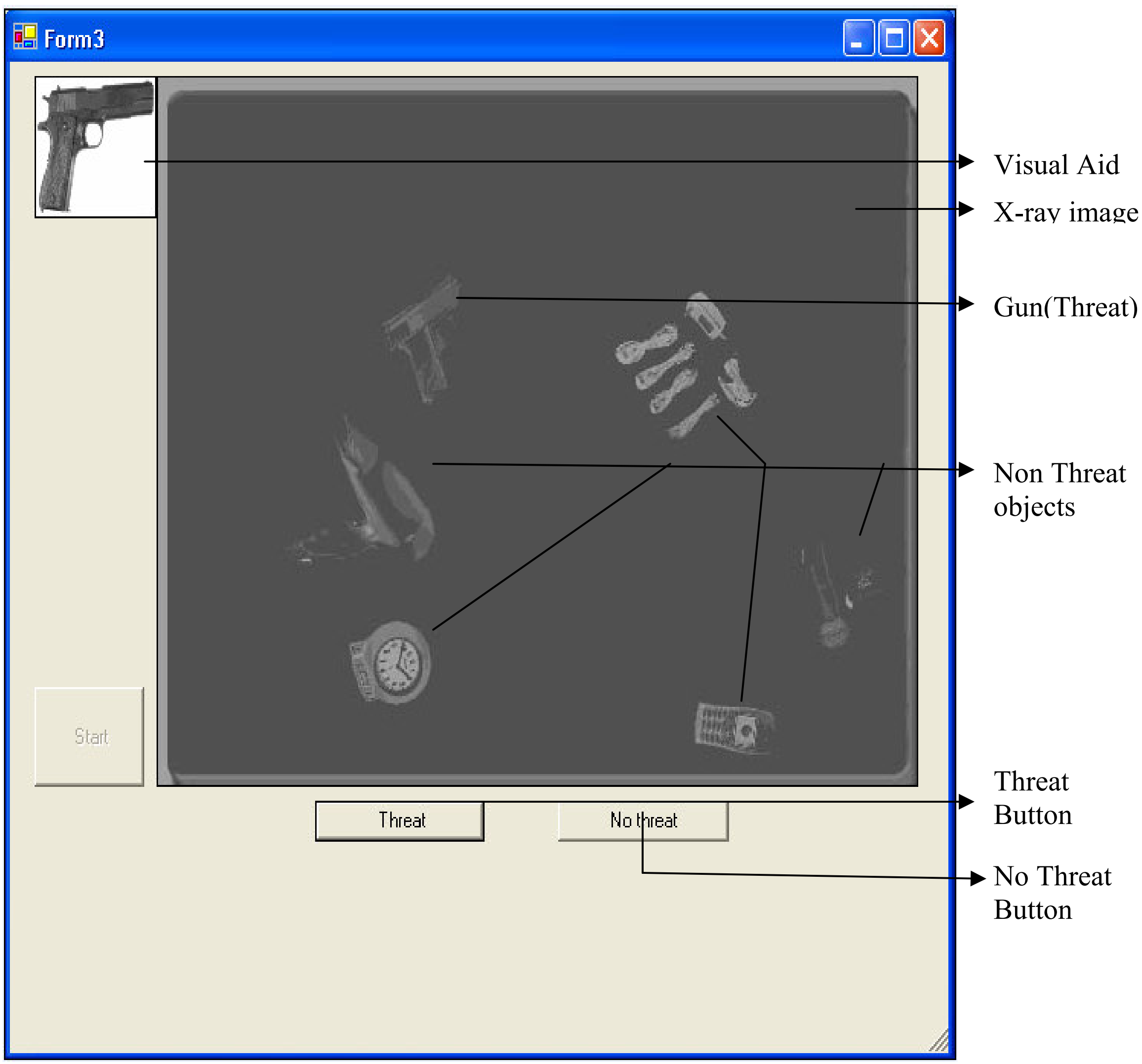


Figure 4: A screen shot of the experimental setup

4.4 Experimental Variables and Their Measures

4.4.1 Dependent Variables

- Time of inspection: Time of inspection is measured as the time from the presentation of image to the participant to the time when the participant identifies the “Threat” or “No Threat”. If the participant does not respond, the response time is noted as the time from the presentation of the image to the participant to the time till the next image is presented to the participant (in this case, the images are paced at 8 seconds per image, so the maximum time of inspection is 8 seconds).
- Accuracy of inspection: Accuracy of inspection is the ratio of the number of correct responses to the total number of responses (total number of responses = correct responses + incorrect responses).

4.4.2 Independent Variables

- Threat objects: Threat objects are the objects that the participants were be made to find from the images presented to them. The threat objects for the experiment were those from the TSA list of permitted and prohibited items on a passenger aircraft (Appendix A).
- Visual aids: Visual aids are decision-making aids presented to the participants to help them find the target object in the x-ray image presented to them. These images appear along with a description at the top left corner of the screen. An example visual aid is shown in Figure 1.
- Degree of rotation of the target object: Degree of rotation is the angle through which the threat object is rotated on in the horizontal plane. The degrees of rotation for the threat object in the experiment were 0, 45,135, 225, 315 degrees.

- Training: Training increases the amount of familiarity that the participant has with the task at hand. Training also provides the participants with the information, procedure and practice needed to improve the inspection task. In this experiment there are two types of training:
    - Basic Training: In basic training, the participants were explained the purpose of the experiment. The participants were then trained to use the simulated x-ray inspection software. They were introduced to the concepts of inspection. They were also given the TSA's list of prohibited items on the plane. This training was given orally.
    - Advanced Training: Participants were introduced to the concepts of mental rotation and eye movements and were also trained to use the simulated software. This training was given orally.

4.5 Experimental Design Procedure

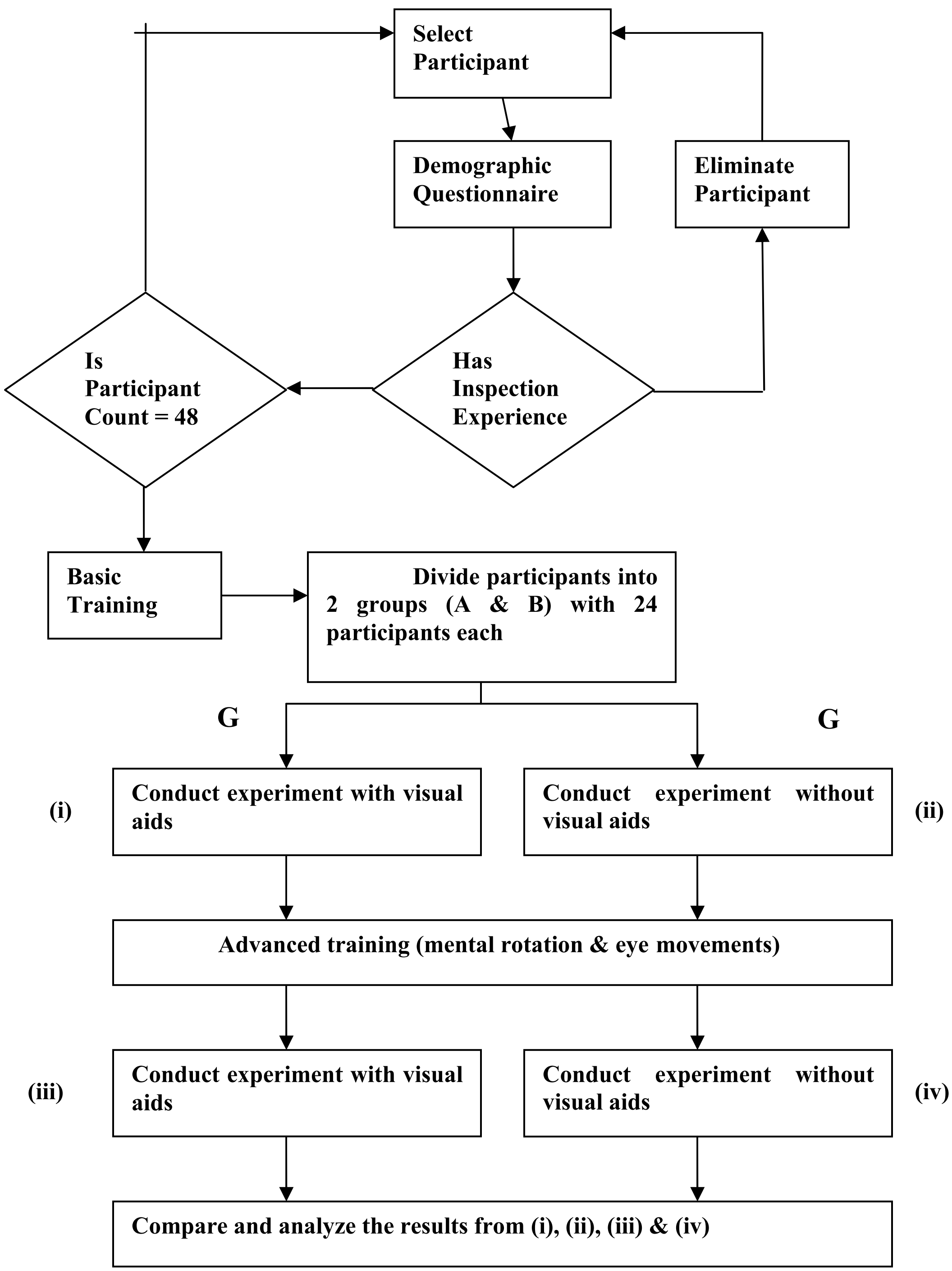
The experimental procedure begins with the selection of participants. The participants were given a demographic questionnaire before the start of the experiment. This questionnaire included questions on participant's demographic details as well as some questions related to the inspection experience. Forty-eight participants with no experience in industrial quality control inspection or airport baggage inspection were selected. These participants were given a basic training session. Then the participants were randomly assigned to one of two conditions (inspection with and inspection without visual aides). Both the groups were presented with the x-ray scanner images as shown in the figure 1. The participants had to check if the image contained any threat objects and if so, they had to identify the threat object. The first group were presented with the x-ray images only. They were not provided with the visual aids that appear on the top left corner of the screen. The second group was presented with the images along with the visual aids. The target or threat objects in the presented images were rotated in the horizontal plane. Each of the participants was presented with 24 images each for a duration of 8 seconds. Out of these, 4 images did not have any target objects. The remaining 20 images had a target object either rotated or un-rotated. These images were presented to the participants in a random order. The following table (Table 2) gives a list of the number combinations degrees of rotation and the number of images presented to the participants.

Table 2: Rotation Angles and Number of Images for Each Rotation Angle

Image Type	**No.of Images**
No threat object	4
Threat object with no rotation (0^0)	4
Threat object with 45^0 rotation	4
Threat object with 135^0 rotation	4
Threat object with 225^0 rotation	4
Threat object with 315^0 rotation	4
TOTAL	24

The response times for each participant in both the groups are found and tabulated. All the participants were then given an advanced training session. The participants then completed the same experiment again. The response times for each participant were captured and noted again. In the first experimental trial, by comparing the times of inspection and the accuracy of the two groups, the effects of visual/job aids on the inspection could be observed. By comparing the inspection times and accuracies of the first group and second group before and after the advanced training, the effects of training could be observed. By comparing the inspection times and accuracies for images with different rotation angles between the two groups during trial 1 or trial 2, effects of mental rotation could be observed.

4.5.1 Chart for Flow of the Experiment



4.5.2 Experimental Task

The participants were given a demographic questionnaire which had to be filled before the start of the experiment. The participants then had to take a basic training session. After the training session, the participant was randomly assigned to condition A (which was the first group or the group which performed the visual search without visual aids) or condition B (which was the group that performed the visual search with visual aids). The participant then started the visual inspection task which consisted of a series of 24 images presented to the participants. The user had to look at the image and decide if there was any threat object. If the participant thought that there was a threat object, then he/she had to identify the threat object by pressing the "Threat" button. Then the participant would be given a set of options by which to select the actual threat object. The participant had to do this within 8 seconds for each image. If the participant thought that there was no threat object, then he/she had to click the no threat button on the screen before the 8 seconds.

After this trial, the participants had to take an advanced training session. After this session, the participants were then placed back in the same condition and the experimental trial was repeated. The results from the two trials were noted and analyzed.

CHAPTER 5. RESULTS AND DISCUSSION

51. Results

The data for all the different cases has been tabulated and presented in Appendix B.

A 3x2 ANOVA was performed on the data to see if there were mental rotation effects, training effects, effects of using visual aids on response times, or interactions between these variables. The results from the ANOVA are tabulated in Table 3.

Table 3: Results of 3x2 ANOVA for Time

Source	Sum of squares	Df	Mean square	F	P
Rotation	88046.59	1	88046.59	27.2584	<.0001*
Training	103390.23	1	103390.23	32.0086	<.0001*
Visual Aids	67001.70	1	67001.70	20.7431	<.0001*
Visual Aids * Training	4068.36	1	4068.36	1.2595	0.2632
Visual Aids * Rotation	1051.47	1	1051.47	0.3255	0.5690
Training * Rotation	27730.56	1	27730.56	8.5851	0.0038*
Visual Aids * Training * Rotation	1418.17	1	1418.17	0.4391	0.5084
Error	594334.27	184	3230.1		
Corrected Total	887041.35	191			

* $p < 0.05$

Table 4: Average Response Times and Standard Deviations

	Average Response times	Standard Deviation	No. of Subjects	Percentage Difference:	Percentage Decrease
With rotated objects	3.64	0.64	48	With and without rotated objects	11.8%
Without rotated objects	3.21	0.65	48		
Before training	3.86	0.45	48	Before and after training	15.8%
After Training	3.25	0.52	48		
Without visual aids	4.03	0.53	24(2 trials each)	With and without aids	8.1%
With visual aids	3.70	0.50	24(2 trials each)		

A 3x2 ANOVA was performed on the data to see if there were training effects and effects of using visual aids on accuracy of inspection, or interactions between these variables. The results from the ANOVA are tabulated in Table 5.

Table 5: Results of 3x2 ANOVA for Accuracy

Source	Sum of squares	Df	Mean square	F	P
Rotation	782.35	1	782.35	7.63	0.0063*
Training	3509.01	1	3509.01	34.23	<.0001*
Visual Aids	2007.3180	1	2007.3180	19.58	<.0001*
Visual Aids * Rotation	0.0897	1	0.0897	0.0009	0.9764
Training * Rotation	0.8073	1	0.8073	0.0079	0.9294
Visual Aids * Training	151.99	1	151.99	1.4829	0.2249
Visual Aids * Training * Rotation	0.0906	1	0.0906	0.0009	0.9763
Error	18858.994	184	102.495		
Corrected Total	25310.646	191			
P<0.05					

Table 6: Average Accuracy of Inspection and Standard Deviations

	Average Accuracy	Standard Deviation	No. of Subjects	Percentage difference:	Percentage increase
Before training	74.73	10.92	48	Before and after training	11.63%
After training	83.42	10.51	48		
With visual aids	75.86	11.69	24(2 trials each)	With and without aids	8.48%
Without visual aids	82.29	10.51	24(2 trials each)		
With rotated objects	75.04	11.20	48	With and without rotated objects	5.38%
Without rotated objects	79.08	11.51	48		

5.2 Hypothesis Analysis Results

Using the results of the above ANOVA, each hypothesis was evaluated. The results are discussed with respect to each hypothesis.

5.2.1 Hypothesis 1

"Inspection time and accuracy will differ for objects that require mental rotation as compared to objects that do not require mental rotation".

Rotated objects significantly affected both time ($F(1, 184) = 27.26$, $p = <0.0001$) to detect an object and operator performance accuracy ($F(1, 184) = 7.63$, $p = 0.0063$). Thus rotated objects significantly affect an operator's time to detect the object as well as their accuracy.

5.2.2 Hypothesis 2

"Inspection performance (e.g. accuracy and time) will improve for inspectors that receive mental rotation training".

With respect to training and mental rotation, Table 3 shows that there was a significant interaction effect between training and rotation for response time, $F(1, 184) = 8.59$, $p = .0038$. A means comparison can bee seen below:

Training	Rotation	Tukey Analysis		Least Sq Mean
No	Yes	A		399.16
No	No		B	332.29
Yes	Yes		B	328.71
Yes	No		B	309.92

As can be seen, individuals that received no training and had rotated objects performed the worse compared to all other conditions. The other conditions were not significantly different from one another. Prospective statistical power analysis was used to ensure sufficient samples were collected for statistical comparisons. A power of 0.83 was found to be sufficient.

A significant difference for accuracy was found for training, $F(1, 184) = 34.23$, $p < 0.0001$. Accuracy for images with training was higher ($M = 83.42$, SD = 10.51) than the accuracy ($M = 74.73$, SD = 10.92) without training. Prospective statistical power analysis was used to ensure sufficient samples were collected for statistical comparisons. A power of 0.99 was deemed sufficient.

5.2.3 Hypothesis 3

"Inspection performance (e.g. accuracy and time) will differ for inspection with visual aids as compared to inspection without visual aids".

A significant difference for response time was found for visual aids, $F(1, 184) = 20.74$, $p = 0.0001$. Response times for images with visual aids was lower ($M = 3.70$ seconds, $SD = 0.50$) than the response times for images after without visual aids ($M = 4.03$ seconds, $SD = 0.53$). Prospective statistical power analysis was used to ensure sufficient samples were collected for statistical comparisons. A power of 0.99 was deemed sufficient.

A significant difference for accuracy was found for visual aids, $F(1, 184) = 19.58$, $p = <0.0001$. Accuracy for images presented with visual aids was higher ($M = 82.29$, SD = 10.51) than the accuracy($M = 75.86$, SD = 11.69) for images presented without visual aids. Prospective statistical power analysis was used to ensure sufficient samples were collected for statistical comparisons. A power of 0.99 was deemed sufficient.

5.3 Discussion

The results from the experiment show that inspection time will differ for objects that require mental rotation as compared to objects that do not require mental rotation. This confirms with the fact that that response times differ with the angle of rotation of the target object. It can also be observed from the results that the inspection times improve from 3.86 seconds to 3.25 seconds by training the participants in mental rotation. Mental rotation training also improved the accuracy from 74.74% to 83.42%. Results from the experiment also show that the use of visual decision-making aids would improve the inspection performance of an airport baggage inspection task. Participants who were provided with the visual decision making aids had an average inspection time of 3.69 seconds and an accuracy of 82.29% and the participants who did not have any visual decision-making aids had an average inspection time of 4.21 and an accuracy of 75.87%.

Thousands of people fly through each airport and each of them carry at least 2 bags on an average. About 100,000 passengers pass through an international airport per day in North America (World Airport Guide, 2005). So, on an average, 200,000 bags need to be checked everyday. By using visual decision-making aids, there was a 0.5 second improvement in the response time for inspection. This time is equal to about 2 blinks of the eye and may look very small when considered for a single baggage. But about 30 minutes of inspection time can be reduced per day for all baggage checked at a typical airport. This would allow more bags, approximately 225, to be processed throughout the day. In short, the productivity of the inspection task can be improved. Moreover, accuracy of inspection can be improved by about 6.5%. By training the inspectors on mental rotation, there can be a 0.6 seconds improvement in the response times for each baggage. This means about 34 minutes of work can be saved every day for all the baggage checks at a typical airport. By training the inspectors for mental rotation, the accuracy can be improved by 8.6%.

5.4 Conclusion

The problem of trying to defend against terrorism is best illustrated in a statement by the Irish Republican Army after a failed attempt to kill British Prime Minister Margaret Thatcher in 1984: ‘‘Remember, we only have to be lucky once. You will have to be lucky always.’’ That is no less true for any government defending against any terrorist activity. Incidents like the one on September 11, 2001 prove this point.

It becomes the duty of airport baggage inspectors to minimize or eliminate any such incidents. Human errors may not be eliminated totally, but the performance can be improved using many techniques. Current research has shown that mental rotation of objects significantly affects response times and accuracy. Training in mental rotation can improve the performance. Though the improvement in time (0.6 seconds) for one bag is small, it becomes considerable when a real scenario where more than 200,000 bags need to be checked at an airport per day. It has also been found that the accuracy of inspection is improved by 8.6% by mental rotation training. When it comes to eliminating a security threat, this improvement in accuracy is very important. Another method to improve the response time and accuracy is providing visual decision-making aids for the inspector. In this case also, the response time is increased by 0.5 seconds. Using visual decision-making aids would improve the accuracy by 6.5%.

Finally, it can be concluded that there are many ways to improve inspection performance of an airport baggage inspector and mental rotation training and providing visual aids are two such ways to improve it.

There are some limitations to the study. Firstly, the x-ray images used in the study were not the exact x-ray images obtained from baggage scanner. Such images were not available for the study due to security reasons. So the x-ray images were created using Adobe Photoshop and made sure that these images are very similar to the original x-ray images. The number of objects in each of these images was kept at 6 or 7 and the positions were randomized. For future research, x-ray images from the baggage scanner needs to be considered. Secondly, the experiment was carried out in the laboratory environment using student subjects. Using the airport environment and carrying out the experiment with already trained security officials would provide more accurate results. Lastly, number of subjects used in the experiment and number of x-ray images each participant would go through was limited by time and availability of the participants. Number of participants and the number of x-ray images each participant scans can be improved to get a larger data set.

Past research has shown that eye movement patterns have an effect on the inspection performance during a quality control inspection task (Megaw & Richardson, 1979). As a part of future research, the effect of eye movements on airport baggage inspection can be observed and ways to improve eye movement patterns can be applied to see if they have any affect on the inspection performance. Future research should also look at some of the airport baggage inspection aspects like presenting the inspector with threat objects which are broken down into smaller components. Based on the current research one can consider the development of an image processing system which could recognize threat objects automatically by their shapes and profiles to provide the inspector with visual decision-making aids.

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APPENDIX A: TSA LIST OF PERMITTED AND PROHIBITED ITEMS ON PASSENGER PLANE

U.S. Department of Homeland Security
Transportation Security Administration
Arlington, VA 22202

Transportation Security Administration

Permitted and Prohibited Items

Prohibited items are weapons, explosives, incendiaries, and include items that are seemingly harmless but may be used as weapons—the so-called "dual use" items. You may not bring these items to security checkpoints without authorization.

If you bring a prohibited item to the checkpoint, you may be criminally and/or civilly prosecuted or, at the least, asked to rid yourself of the item. A screener and/or Law Enforcement Officer will make this determination, depending on what the item is and the circumstances. This is because bringing a prohibited item to a security checkpoint—even accidentally—is illegal.

Your prohibited item may be detained for use in an investigation and, if necessary, as evidence in your criminal and/or civil prosecution. If permitted by the screener or Law Enforcement Officer, you may be allowed to: consult with the airlines for possible assistance in placing the prohibited item in checked baggage; withdraw with the item from the screening checkpoint at that time; make other arrangements for the item, such as taking it to your car; or, voluntarily abandon the item. Items that are voluntarily abandoned cannot be recovered and will not be returned to you.

The following chart outlines items that are permitted and items that are prohibited in your carry-on or checked baggage. You should note that some items are allowed in your checked baggage, but not your carry-on. Also pay careful attention to the "Notes" included at the bottom of each section – they contain important information about restrictions.

The prohibited and permitted items chart is not intended to be all-inclusive and is updated as necessary. To ensure everyone's security, the screener may determine that an item not on the prohibited items chart is prohibited. In addition, the screener may also determine that an item on the permitted chart is dangerous and therefore may not be brought through the security checkpoint.

The chart applies to flights originating within the United States. Please check with your airline or travel agent for restrictions at destinations outside of the United States.

For updates and for more information, call our Consumer Response Center toll-free at 1-866-289-9673 or email TSA-ContactCenter@dhs.gov.

U.S. Department of Homeland Security
Transportation Security Administration
Arlington, VA 22202

Transportation Security Administration

Permitted and Prohibited Items

Can I take it?	Carry-on	Checked
Personal Items		
Cigar Cutters	Yes	Yes
Corkscrews	Yes	Yes
Cuticle Cutters	Yes	Yes
Eyeglass Repair Tools (including screwdrivers)	Yes	Yes
Eyelash Curlers	Yes	Yes
Knitting and Crochet Needles	Yes	Yes
Knives, round-bladed butter or plastic	Yes	Yes
Nail Clippers	Yes	Yes
Nail Files	Yes	Yes
Personal care or toiletries with aerosols, in limited quantities (such as hairsprays, deodorants)	Yes	Yes
Safety Razors (including disposable razors)	Yes	Yes
Scissors-plastic or metal with blunt tips	Yes	Yes
Scissors-metal with pointed tips	No	Yes
Toy Transformer Robots	Yes	Yes
Toy Weapons (if not realistic replicas)	Yes	Yes
Tweezers	Yes	Yes
Umbrellas (allowed in carry-on baggage once they have been inspected to ensure that prohibited items are not concealed)	Yes	Yes
Walking Canes (allowed in carry-on baggage once they have been inspected to ensure that prohibited items are not concealed)	Yes	Yes
Note Some personal care items containing aerosol are regulated as hazardous materials. The FAA regulates hazardous materials. This information is summarized at http://asi.faa.gov/Passenger.asp		
Medication and Special Needs Devices		
Braille Note-Taker, Slate and Stylus, Augmentation Devices	Yes	Yes
Diabetes-Related Supplies/Equipment, (once inspected to ensure prohibited items are not concealed) including: insulin and insulin loaded dispensing products; vials or box of individual vials; jet injectors; pens; infusers; and preloaded syringes; and an unlimited number of unused syringes, when accompanied by insulin; lancets; blood glucose meters; blood glucose meter test strips; insulin pumps; and insulin pump supplies. Insulin in any form or dispenser must be properly marked with a professionally printed label identifying the medication or manufacturer's name or pharmaceutical label.	Yes	Yes
Nitroglycerine pills or spray for medical use (if properly marked with a professionally printed label identifying the medication or manufacturer's name or pharmaceutical label)	Yes	Yes
Prosthetic Device Tools and Appliances, including drill, allen wrenches, pullsleeves used to put on or remove prosthetic devices, if carried by the individual with the prosthetic device or his or her companion	Yes	Yes

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Arlington, VA 22202

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Permitted and Prohibited Items

Can I take it?	Carry-on	Checked
Electronic Devices		
Camcorders	Yes	Yes
Camera Equipment The checked baggage screening equipment will damage undeveloped film in camera equipment. We recommend that you either put undeveloped film and cameras containing undeveloped film in your carry-on baggage or take undeveloped film with you to the checkpoint and ask the screener to conduct a hand-inspection.	Yes	Yes
Laptop Computers	Yes	Yes
Mobile Phones	Yes	Yes
Pagers	Yes	Yes
Personal Data Assistants (PDA's)	Yes	Yes
Note Check with your airline or travel agent for restrictions on the use of these and other electronic items during your flight.		
Sharp Objects		
Box Cutters	No	Yes
Ice Axes/Ice Picks	No	Yes
Knives (any length and type except round-bladed, butter, and plastic cutlery)	No	Yes
Meat Cleavers	No	Yes
Razor-Type Blades, such as box cutters, utility knives, razor blades not in a cartridge, but excluding safety razors	No	Yes
Sabers	No	Yes
Scissors – metal with pointed tips Scissors with plastic or metal blunt tips are permitted in your carry-on.	No	Yes
Swords	No	Yes
Note Any sharp objects in checked baggage should be sheathed or securely wrapped to prevent injury to baggage handlers and inspectors.		
Sporting Goods		
Baseball Bats	No	Yes
Bows and Arrows	No	Yes
Cricket Bats	No	Yes
Golf Clubs	No	Yes
Hockey Sticks	No	Yes
Lacrosse Sticks	No	Yes
Pool Cues	No	Yes
Ski Poles	No	Yes
Spear Guns	No	Yes
Note Any sharp objects in checked baggage should be sheathed or securely wrapped to prevent injury to baggage handlers and security screeners.		

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Permitted and Prohibited Items

Can I take it?	Carry-on	Checked
Guns and Firearms		
Ammunition Check with your airline or travel agent to see if ammunition is permitted in checked baggage on the airline you are flying. If ammunition is permitted, it must be declared to the airline at check-in. Small arms ammunitions for personal use must be securely packed in fiber, wood or metal boxes, or other packaging specifically designed to carry small amounts of ammunition. Ask about limitations or fees, if any, that apply.	No	Yes
BB guns	No	Yes
Compressed Air Guns	No	Yes
Firearms	No	Yes
Flare Guns	No	**No**
Gun Lighters	No	**No**
Gun Powder	No	**No**
Parts of Guns and Firearms	No	Yes
Pellet Guns	No	Yes
Realistic Replicas of Firearms	No	Yes
Starter Pistols	No	Yes
Note Check with your airline or travel agent to see if firearms are permitted in checked baggage on the airline you are flying. Ask about limitations or fees, if any, that apply. Firearms carried as checked baggage MUST be unloaded, packed in a locked hard-sided gun case, and declared to the airline at check-in. Only you, the passenger, may have the key or combination.		
Tools		
Axes and Hatchets	No	Yes
Cattle Prods	No	Yes
Crowbars	No	Yes
Hammers	No	Yes
Drills (including cordless portable power drills)	No	Yes
Saws (including cordless portable power saws)	No	Yes
Screwdrivers (except those in eyeglass repair kits)	No	Yes
Tools (including but not limited to wrenches and pliers)	No	Yes
Wrenches and Pliers	No	Yes
Note Any sharp objects in checked baggage should be sheathed or securely wrapped to prevent injury to baggage handlers and security screeners.		
Martial Arts/Self Defense Items		
Billy Clubs	No	Yes
Black Jacks	No	Yes
Brass Knuckles	No	Yes
Kubatons	No	Yes
Mace/Pepper Spray One 118 ml or 4 Fl. oz. container of mace or pepper spray is permitted in checked baggage provided it is equipped with a safety mechanism to prevent accidental discharge. For more information on these and other hazardous materials, visit http://asi.faa.gov/Passenger.asp	No	Yes
Martial Arts Weapons	No	Yes
Night Sticks	No	Yes
Nunchakus	No	Yes

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Transportation Security Administration
Arlington, VA 22202

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Permitted and Prohibited Items

Can I take it?	Carry-on	Checked
Martial Arts/Self Defense Items		
Stun Guns/Shocking Devices	No	Yes
Throwing Stars	No	Yes
Note Any sharp objects in checked baggage should be sheathed or securely wrapped to prevent injury to baggage handlers and security screeners.		
Explosive Materials		
Blasting Caps	No	No
Dynamite	No	No
Fireworks	No	No
Flares (in any form)	No	No
Hand Grenades	No	No
Plastic Explosives	No	No
Realistic Replicas of Explosives	No	No
Flammable Items		
Aerosol (any except for personal care or toiletries in limited quantities)	No	No
Fuels (including cooking fuels and any flammable liquid fuel)	No	No
Gasoline	No	No
Gas Torches	No	No
Lighters *	No	No
Lighter Fluid	No	No
Strike-anywhere Matches	No	No
Turpentine and Paint Thinner	No	No
Realistic Replicas of Incendiaries	No	No
Beginning April 14, 2005, all lighters will be prohibited as carry-on items. Up to four (4) books of safety matches are permitted as carry-on only. Lighters and Matches are always prohibited in checked baggage. Note There are other hazardous materials that are regulated by the FAA. This information is summarized at http://asi.faa.gov/Passenger.asp		
Disabling Chemicals and Other Dangerous Items		
Chlorine for Pools and Spas	No	No
Compressed Gas Cylinders (including fire extinguishers)	No	No
Liquid Bleach	No	No
Spillable Batteries (except those in wheelchairs)	No	No
Spray Paint	No	No
Tear Gas	No	No
Note There are other hazardous materials that are regulated by the FAA. This information is summarized at http://asi.faa.gov/Passenger.asp		

APPENDIX B: RESULTS

Response time for 0 degrees rotation and some degree of rotation (Data).

Rotation	
Response time	
0 degrees Rotation	Some Angle of Rotation
387.00	484.00
231.00	500.19
320.25	330.63
272.25	356.06
327.75	345.94
212.50	386.81
294.75	373.06
327.25	369.50
257.25	438.31
195.50	254.50
222.50	412.50
236.25	320.44
366.75	369.81
466.25	333.94
255.25	385.06
408.50	268.88
369.50	379.44
442.50	407.31
276.25	360.31
507.25	441.31
402.00	436.31
288.00	266.75
335.75	422.13
301.75	270.38
383.25	409.19
355.75	314.19
302.25	391.56
358.75	319.13
459.75	377.75
283.25	261.94
384.00	436.06
320.00	452.25
309.25	362.88
333.50	297.69
369.50	348.38
134.75	249.13
367.00	416.50
315.25	334.50
336.75	418.38
290.25	350.50
324.00	508.88

Response time	
0 degrees Rotation	**Some Angle of Rotation**
335.25	458.50
295.50	436.69
296.25	397.88
400.75	287.19
241.50	392.44
381.25	249.06
379.50	404.81
400.75	324.19
278.25	383.88
293.25	247.50
455.00	442.69
307.00	346.19
294.25	386.19
276.75	321.44
438.25	483.50
362.25	343.31
337.25	350.75
213.50	296.19
373.75	444.88
387.00	338.38
316.00	405.44
309.25	293.75
350.75	522.38
314.75	297.75
320.75	369.13
257.25	286.69
355.25	508.69
356.50	414.38
341.00	391.38
303.75	326.75
353.75	411.38
240.50	303.19
422.50	328.69
218.50	289.06
344.25	413.25
369.00	330.31
294.75	346.81
273.50	323.56
284.25	403.13
276.50	368.13
295.50	342.63
239.50	341.63
317.75	422.00
289.50	304.38
240.25	295.38
214.75	275.75

Response time	
0 degrees Rotation	**Some Angle of Rotation**
339.75	409.50
304.00	392.31
297.00	321.63
288.50	288.31
282.75	354.56
386.75	311.44
313.75	361.00
256.50	298.63

Response time and Accuracy before training and after training (Data).

Training			
Response Time		Accuracy	
Before Training	After Training	Before Training	After Training
464.60	446.35	75.00	50.00
328.55	339.30	91.67	95.83
342.30	351.95	62.50	87.50
357.40	361.05	62.50	70.83
402.10	242.70	66.67	100.00
374.50	303.60	87.50	95.83
369.20	360.40	79.17	83.33
359.10	296.80	75.00	83.33
377.45	414.35	75.00	91.67
343.50	454.50	70.83	66.67
429.45	271.00	70.83	83.33
404.85	276.65	75.00	87.50
404.00	322.50	66.67	79.17
373.70	327.05	79.17	75.00
394.15	266.20	66.67	83.33
425.65	425.80	66.67	79.17
352.15	304.85	70.83	75.00
352.60	226.25	66.67	91.67
406.60	330.65	75.00	83.33
402.05	338.45	62.50	79.17
471.90	384.95	75.00	83.33
433.85	408.45	62.50	66.67
377.55	309.90	66.67	83.33
362.25	275.50	75.00	87.50
399.75	339.50	75.00	79.17
362.75	256.65	79.17	87.50
445.15	338.35	83.33	83.33
367.80	312.50	91.67	100.00
474.45	347.10	79.17	87.50
348.05	279.65	79.17	87.50
430.65	348.10	66.67	79.17
387.55	296.85	75.00	83.33
488.05	301.15	41.67	54.17
359.45	280.80	83.33	83.33
478.00	402.80	75.00	87.50
381.30	322.15	79.17	83.33
399.85	290.65	70.83	87.50
347.45	274.95	95.83	100.00
399.45	338.05	87.50	70.83
336.40	313.55	83.33	87.50
379.35	349.80	66.67	87.50
333.20	321.20	100.00	95.83

Response Time		Accuracy	
Before Training	**After Training**	**Before Training**	**After Training**
401.15	301.40	79.17	66.67
284.35	263.55	75.00	91.67
395.55	374.65	50.00	91.67
316.70	288.35	91.67	91.67
340.20	326.50	70.83	87.50
351.55	290.20	83.33	87.50

Response time and Accuracy with Visual Aids and without Visual Aids (Data).

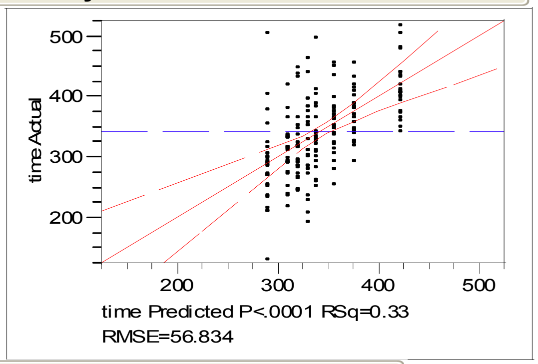
Visual Aids			
Response Time		Accuracy	
No Visual Aids	With Visual Aids	No Visual Aida	With Visual Aids
490.04	326.88	75.00	91.67
440.21	324.00	50.00	95.83
369.54	391.75	62.50	62.50
343.08	390.21	87.50	70.83
424.00	415.71	66.67	87.50
310.00	364.50	100.00	95.83
393.50	406.08	79.17	75.00
402.21	334.33	83.33	83.33
412.21	402.92	75.00	70.83
442.50	480.16	91.67	66.67
465.58	428.50	70.83	75.00
322.50	333.33	83.33	87.50
429.08	401.88	66.67	79.17
354.58	380.50	79.17	75.00
434.00	469.04	66.67	66.67
311.13	431.04	83.33	79.17
368.25	342.21	70.83	66.67
348.38	262.54	75.00	91.67
434.17	415.17	75.00	62.50
351.58	346.42	83.33	79.17
511.17	453.13	75.00	62.50
413.38	422.71	83.33	66.67
430.21	389.08	66.67	75.00
349.71	312.17	83.33	87.50
446.04	396.25	75.00	79.17
358.88	300.71	79.17	87.50
475.71	403.63	83.33	91.67
377.67	343.71	83.33	100.00
484.38	397.71	79.17	79.17
391.79	356.63	87.50	87.50
459.54	440.08	66.67	75.00
364.00	349.00	79.17	83.33
492.08	370.50	41.67	83.33
321.58	292.88	54.17	83.33
490.58	432.92	75.00	79.17
436.88	363.54	87.50	83.33
421.08	401.50	70.83	95.83
326.00	322.42	87.50	100.00
440.42	333.29	87.50	83.33
390.21	303.33	70.83	87.50
401.46	374.92	66.67	100.00
375.88	350.42	87.50	95.83

Response Time		Accuracy	
No Visual Aids	**With Visual Aids**	**No Visual Aida**	**With Visual Aids**
423.08	326.83	79.17	75.00
348.08	294.08	66.67	91.67
418.17	353.58	50.00	91.67
395.75	304.17	91.67	91.67
388.33	396.79	70.83	83.33
357.08	320.63	87.50	87.50

ANALYSIS I (3x2 ANOVA for time)

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.329981
RSquare Adj	0.304491
Root Mean Square Error	56.83377
Mean of Response	342.5186
Observations (or Sum Wgts)	192

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	292707.08	41815.3	12.9456
Error	184	594334.27	3230.1	Prob > F
C. Total	191	887041.35		<.0001

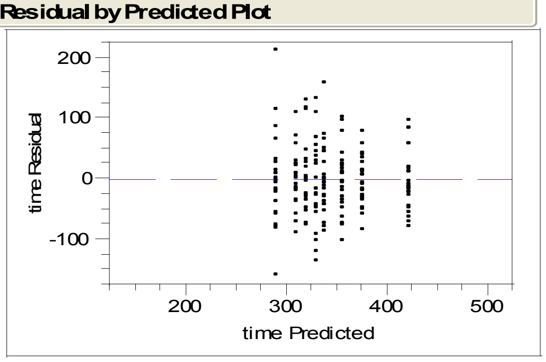
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	342.51855	4.101624	83.51	<.0001
Visual Aids[0]	18.680664	4.101624	4.55	<.0001
Mental Rotation Training[0]	23.205404	4.101624	5.66	<.0001
Visual Aids[0]*Mental Rotation Training[0]	4.6031901	4.101624	1.12	0.2632
Rotation[0]	-21.41439	4.101624	-5.22	<.0001
Visual Aids[0]*Rotation[0]	2.3401693	4.101624	0.57	0.5690
Mental Rotation Training[0]*Rotation[0]	-12.0179	4.101624	-2.93	0.0038
Visual Aids[0]*Mental Rotation Training[0]*Rotation[0]	-2.717773	4.101624	-0.66	0.5084

Effect Tests

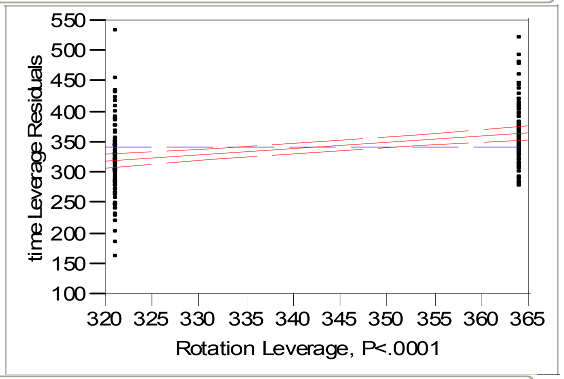
Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Visual Aids	1	1	67001.70	20.7431	<.0001
Mental Rotation Training	1	1	103390.23	32.0086	<.0001
Visual Aids*Mental Rotation Training	1	1	4068.36	1.2595	0.2632
Rotation	1	1	88046.59	27.2584	<.0001
Visual Aids*Rotation	1	1	1051.47	0.3255	0.5690
Mental Rotation Training*Rotation	1	1	27730.56	8.5851	0.0038
Visual Aids*Mental Rotation Training*Rotation	1	1	1418.17	0.4391	0.5084

Residual by Predicted Plot



Rotation

Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
0	321.10417	5.8005725	321.104
1	363.93294	5.8005725	363.933

LSMeans Differences Tukey HSD

Alpha= 0.050 Q= 1.97294

LSMean[j]

LSMean[i]	Mean[i]-Mean[j] Std Err Dif Lower CL Dif Upper CL Dif	0	1
	0	0 0 0 0	-42.829 8.20325 -59.013 -26.644
	1	42.8288 8.20325 26.6443 59.0133	0 0 0 0

Level			Least Sq Mean
1	A		363.93294
0		B	321.10417

Levels not connected by same letter are significantly different

Power Details

Test Rotation

Power

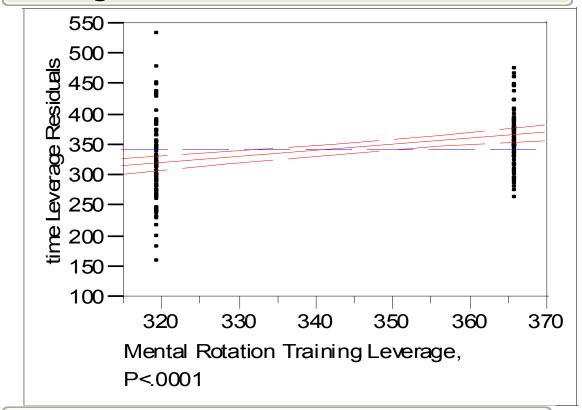
Alpha	Sigma	Delta	Number	Power
0.0500	56.83377	21.41439	192	0.9994

Least Significant Number

Alpha	Sigma	Delta	Number(LSN)
0.0500	56.83377	21.41439	30.25406

Mental Rotation Training

Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
0	365.72396	5.8005725	365.724
1	319.31315	5.8005725	319.313

LSMeans Differences Tukey HSD

Alpha= 0.050 Q= 1.97294

LSMean[i]	Mean[i]-Mean[j] Std Err Dif Lower CL Dif Upper CL Dif	LSMean[j] 0	LSMean[j] 1
	0	0 0 0 0	46.4108 8.20325 30.2263 62.5953
	1	-46.411 8.20325 -62.595 -30.226	0 0 0 0

Level			Least Sq Mean
0	A		365.72396
1		B	319.31315

Levels not connected by same letter are significantly different

Power Details

Test Mental Rotation Training

Power

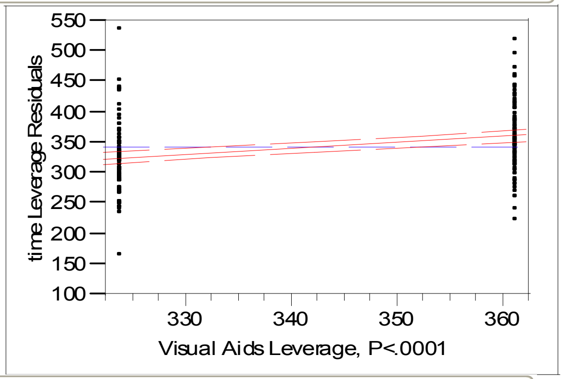
Alpha	Sigma	Delta	Number	Power
0.0500	56.83377	23.2054	192	0.9999

Least Significant Number

Alpha	Sigma	Delta	Number(LSN)
0.0500	56.83377	23.2054	26.3946

Visual Aids

Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
0	361.19922	5.8005725	361.199
1	323.83789	5.8005725	323.838

LSMeans Differences Tukey HSD

Alpha= 0.050 Q= 1.97294

LSMean[i]	Mean[i]-Mean[j] / Std Err Dif / Lower CL Dif / Upper CL Dif	LSMean[j] 0	LSMean[j] 1
0	Mean[i]-Mean[j]	0	37.3613
	Std Err Dif	0	8.20325
	Lower CL Dif	0	21.1768
	Upper CL Dif	0	53.5459
1	Mean[i]-Mean[j]	-37.361	0
	Std Err Dif	8.20325	0
	Lower CL Dif	-53.546	0
	Upper CL Dif	-21.177	0

Level			Least Sq Mean
0	A		361.19922
1		B	323.83789

Levels not connected by same letter are significantly different

Power Details

Test Visual Aids

Power

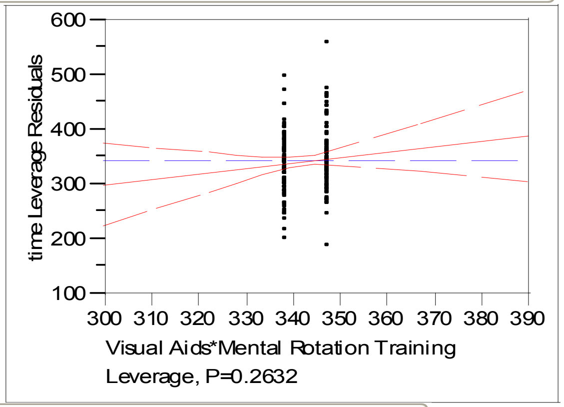
Alpha	Sigma	Delta	Number	Power
0.0500	56.83377	18.68066	192	0.9949

Least Significant Number

Alpha	Sigma	Delta	Number(LSN)
0.0500	56.83377	18.68066	38.54699

Visual Aids*Mental Rotation Training

Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error
0,0	389.00781	8.2032483
0,1	333.39063	8.2032483
1,0	342.44010	8.2032483
1,1	305.23568	8.2032483

Power Details

Test Visual Aids*Mental Rotation Training

Power

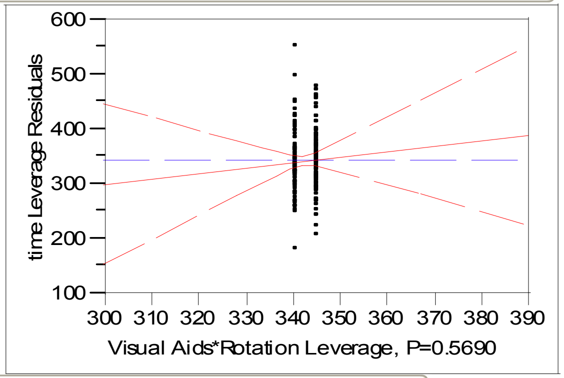
Alpha	Sigma	Delta	Number	Power
0.0500	56.83377	4.60319	192	0.2005

Least Significant Number

Alpha	Sigma	Delta	Number(LSN)
0.0500	56.83377	4.60319	588.0383

Visual Aids*Rotation

Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error
0,0	342.12500	8.2032483
0,1	380.27344	8.2032483
1,0	300.08333	8.2032483
1,1	347.59245	8.2032483

Power Details

Test Visual Aids*Rotation

Power

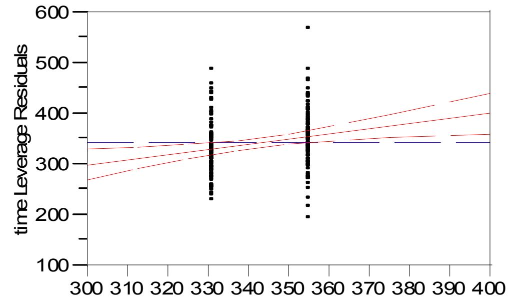
Alpha	Sigma	Delta	Number	Power
0.0500	56.83377	2.340169	192	0.0876

Least Significant Number

Alpha	Sigma	Delta	Number(LSN)
0.0500	56.83377	2.340169	2268.192

Mental Rotation Training*Rotation

Leverage Plot



Mental Rotation Training*Rotation
Leverage, P=0.0038

Least Squares Means Table

Level	Least Sq Mean	Std Error
0,0	332.29167	8.2032483
0,1	399.15625	8.2032483
1,0	309.91667	8.2032483
1,1	328.70964	8.2032483

LSMeans Differences Tukey HSD

Alpha= 0.050 Q= 2.59268

LSMean[j]

LSMean[i]	Mean[i]-Mean[j] Std Err Dif Lower CL Dif Upper CL Dif	0,0	0,1	1,0	1,1
0,0		0	-66.865	22.375	3.58203
		0	11.6011	11.6011	11.6011
		0	-96.943	-7.703	-26.496
		0	-36.787	52.453	33.6601
0,1		66.8646	0	89.2396	70.4466
		11.6011	0	11.6011	11.6011
		36.7865	0	59.1615	40.3686
		96.9426	0	119.318	100.525
1,0		-22.375	-89.24	0	-18.793
		11.6011	11.6011	0	11.6011
		-52.453	-119.32	0	-48.871
		7.70304	-59.162	0	11.2851
1,1		-3.582	-70.447	18.793	0
		11.6011	11.6011	11.6011	0
		-33.66	-100.52	-11.285	0
		26.496	-40.369	48.871	0

Level			Least Sq Mean
0,1	A		399.15625
0,0		B	332.29167
1,1		B	328.70964
1,0		B	309.91667

Levels not connected by same letter are significantly different

Power Details

Test Mental Rotation Training*Rotation

Power

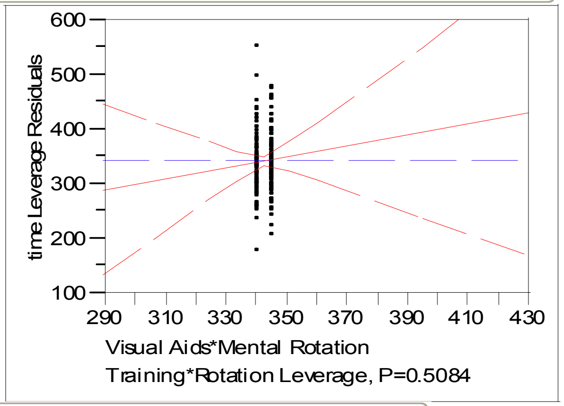
Alpha	Sigma	Delta	Number	Power
0.0500	56.83377	12.0179	192	0.8301

Least Significant Number

Alpha	Sigma	Delta	Number(LSN)
0.0500	56.83377	12.0179	88.55192

Visual Aids*Mental Rotation Training*Rotation

Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error
0,0,0	355.19792	11.601145
0,0,1	422.81771	11.601145
0,1,0	329.05208	11.601145
0,1,1	337.72917	11.601145
1,0,0	309.38542	11.601145
1,0,1	375.49479	11.601145
1,1,0	290.78125	11.601145
1,1,1	319.69010	11.601145

Power Details

Test Visual Aids*Mental Rotation Training*Rotation

Power

Alpha	Sigma	Delta	Number	Power
0.0500	56.83377	2.717773	192	0.1011

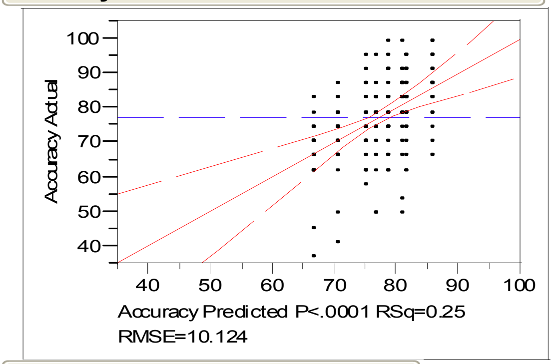
Least Significant Number

Alpha	Sigma	Delta	Number(LSN)
0.0500	56.83377	2.717773	1682.328

ANALYSIS II (3x2 ANOVA for accuracy)

Whole Model

Actual by Predicted Plot



Summary of Fit

RSquare	0.254899
RSquare Adj	0.226552
Root Mean Square Error	10.12396
Mean of Response	77.06151
Observations (or Sum Wgts)	192

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	7	6451.652	921.665	8.9923
Error	184	18858.994	102.495	Prob > F
C. Total	191	25310.646		<.0001

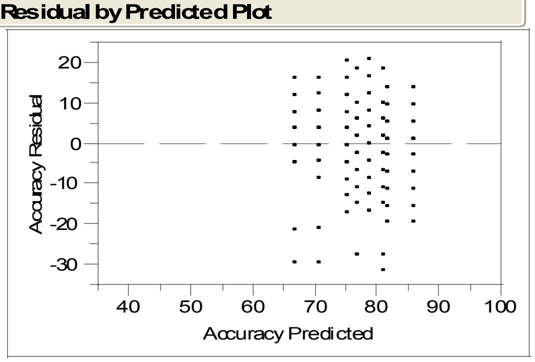
Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	77.06151	0.730634	105.47	<.0001
Visual Aids[0]	-3.233385	0.730634	-4.43	<.0001
Training[0]	-4.275052	0.730634	-5.85	<.0001
Visual Aids[0]*Training[0]	-0.88974	0.730634	-1.22	0.2249
Rotation[0]	2.0185938	0.730634	2.76	0.0063
Visual Aids[0]*Rotation[0]	0.0216146	0.730634	0.03	0.9764
Training[0]*Rotation[0]	-0.064844	0.730634	-0.09	0.9294
Visual Aids[0]*Training[0]*Rotation[0]	0.0217187	0.730634	0.03	0.9763

Effect Tests

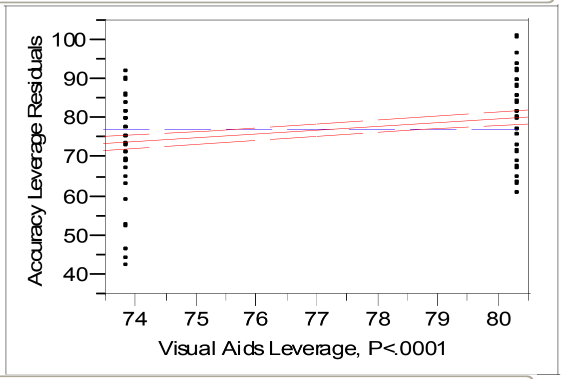
Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Visual Aids	1	1	2007.3180	19.5846	<.0001
Training	1	1	3509.0055	34.2360	<.0001
Visual Aids*Training	1	1	151.9942	1.4829	0.2249
Rotation	1	1	782.3464	7.6331	0.0063
Visual Aids*Rotation	1	1	0.0897	0.0009	0.9764
Training*Rotation	1	1	0.8073	0.0079	0.9294
Visual Aids*Training*Rotation	1	1	0.0906	0.0009	0.9763

Residual by Predicted Plot



Visual Aids

Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
0	73.828125	1.0332722	73.8281
1	80.294896	1.0332722	80.2949

LSMeans Differences Tukey HSD

Alpha= 0.050 Q= 1.97294

LSMean[i]	Mean[i]-Mean[j] Std Err Dif Lower CL Dif Upper CL Dif	LSMean[j] 0	LSMean[j] 1
	0	0 0 0 0	-6.4668 1.46127 -9.3498 -3.5838
	1	6.46677 1.46127 3.58378 9.34977	0 0 0 0

Level			Least Sq Mean
1	A		80.294896
0		B	73.828125

Levels not connected by same letter are significantly different

Power Details

Test Visual Aids

Power

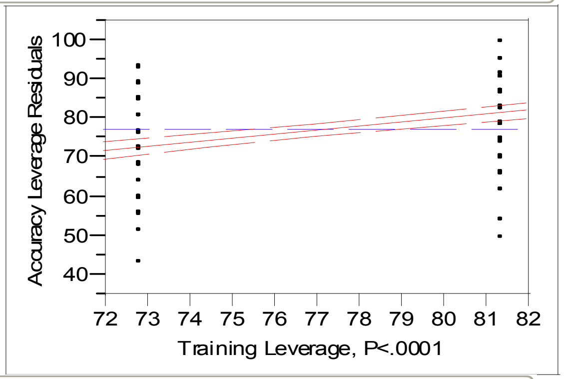
Alpha	Sigma	Delta	Number	Power
0.0500	10.12396	3.233385	192	0.9927

Least Significant Number

Alpha	Sigma	Delta	Number(LSN)
0.0500	10.12396	3.233385	40.61467

Training

Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
0	72.786458	1.0332722	72.7865
1	81.336562	1.0332722	81.3366

LSMeans Differences Tukey HSD

Alpha= 0.050 Q= 1.97294

LSMean[j]

LSMean[i]	Mean[i]-Mean[j] Std Err Dif Lower CL Dif Upper CL Dif	0	1
	0	0 0 0 0	-8.5501 1.46127 -11.433 -5.6671
	1	8.5501 1.46127 5.66711 11.4331	0 0 0 0

Level		Least Sq Mean
1	A	81.336562
0	B	72.786458

Levels not connected by same letter are significantly different

Power Details

Test Training

Power

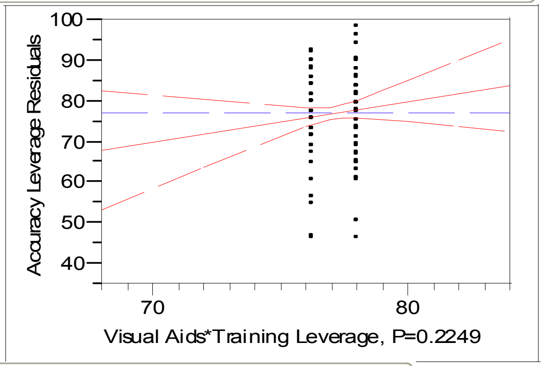
Alpha	Sigma	Delta	Number	Power
0.0500	10.12396	4.275052	192	0.9999

Least Significant Number

Alpha	Sigma	Delta	Number(LSN)
0.0500	10.12396	4.275052	24.97007

Visual Aids*Training

Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error
0,0	68.663333	1.4612675
0,1	78.992917	1.4612675
1,0	76.909583	1.4612675
1,1	83.680208	1.4612675

LSMeans Differences Tukey HSD

Alpha= 0.050 Q= 2.59268

LSMean[j]

LSMean[i]	Mean[i]-Mean[j] Std Err Dif Lower CL Dif Upper CL Dif	0,0	0,1	1,0	1,1
0,0		0	-10.33	-8.2463	-15.017
		0	2.06654	2.06654	2.06654
		0	-15.687	-13.604	-20.375
		0	-4.9717	-2.8884	-9.659
0,1		10.3296	0	2.08333	-4.6873
		2.06654	0	2.06654	2.06654
		4.9717	0	-3.2746	-10.045
		15.6875	0	7.44122	0.67059
1,0		8.24625	-2.0833	0	-6.7706
		2.06654	2.06654	0	2.06654
		2.88837	-7.4412	0	-12.129
		13.6041	3.27455	0	-1.4127
1,1		15.0169	4.68729	6.77062	0
		2.06654	2.06654	2.06654	0
		9.65899	-0.6706	1.41274	0
		20.3748	10.0452	12.1285	0

Level				Least Sq Mean
1,1	A			83.680208
0,1	A	B		78.992917
1,0		B		76.909583
0,0			C	68.663333

Levels not connected by same letter are significantly different

Power Details

Test Visual Aids*Training

Power

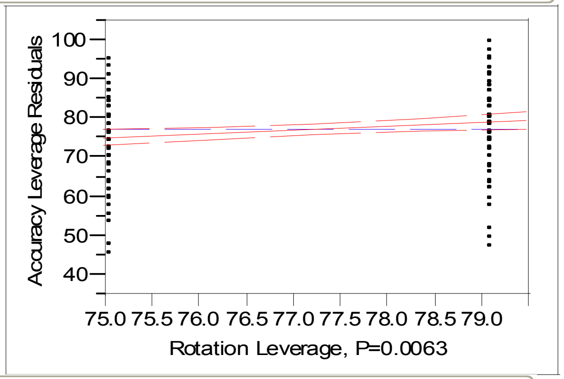
Alpha	Sigma	Delta	Number	Power
0.0500	10.12396	0.88974	192	0.2278

Least Significant Number

Alpha	Sigma	Delta	Number(LSN)
0.0500	10.12396	0.88974	499.8172

Rotation

Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error	Mean
0	79.080104	1.0332722	79.0801
1	75.042917	1.0332722	75.0429

LSMeans Differences Tukey HSD

Alpha= 0.050 Q= 1.97294

LSMean[j]

LSMean[i]	Mean[i]-Mean[j] Std Err Dif Lower CL Dif Upper CL Dif	0	1
	0	0 0 0 0	4.03719 1.46127 1.15419 6.92018
	1	-4.0372 1.46127 -6.9202 -1.1542	0 0 0 0

Level			Least Sq Mean
0	A		79.080104
1		B	75.042917

Levels not connected by same letter are significantly different

Power Details

Test Rotation

Power

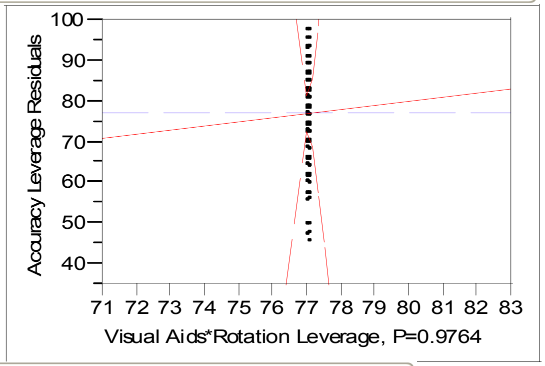
Alpha	Sigma	Delta	Number	Power
0.0500	10.12396	2.018594	192	0.7848

Least Significant Number

Alpha	Sigma	Delta	Number(LSN)
0.0500	10.12396	2.018594	99.24194

Visual Aids*Rotation

Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error
0,0	75.868333	1.4612675
0,1	71.787917	1.4612675
1,0	82.291875	1.4612675
1,1	78.297917	1.4612675

LSMeans Differences Tukey HSD

Alpha= 0.050 Q= 2.59268

LSMean[j]

LSMean[i]	Mean[i]-Mean[j] Std Err Dif Lower CL Dif Upper CL Dif	0,0	0,1	1,0	1,1
0,0	Mean[i]-Mean[j]	0	4.08042	-6.4235	-2.4296
	Std Err Dif	0	2.06654	2.06654	2.06654
	Lower CL Dif	0	-1.2775	-11.781	-7.7875
	Upper CL Dif	0	9.4383	-1.0657	2.9283
0,1	Mean[i]-Mean[j]	-4.0804	0	-10.504	-6.51
	Std Err Dif	2.06654	0	2.06654	2.06654
	Lower CL Dif	-9.4383	0	-15.862	-11.868
	Upper CL Dif	1.27747	0	-5.1461	-1.1521
1,0	Mean[i]-Mean[j]	6.42354	10.504	0	3.99396
	Std Err Dif	2.06654	2.06654	0	2.06654
	Lower CL Dif	1.06566	5.14607	0	-1.3639
	Upper CL Dif	11.7814	15.8618	0	9.35184
1,1	Mean[i]-Mean[j]	2.42958	6.51	-3.994	0
	Std Err Dif	2.06654	2.06654	2.06654	0
	Lower CL Dif	-2.9283	1.15212	-9.3518	0
	Upper CL Dif	7.78747	11.8679	1.36393	0

Level				Least Sq Mean
1,0	A			82.291875
1,1	A	B		78.297917
0,0		B	C	75.868333
0,1			C	71.787917

Levels not connected by same letter are significantly different

Power Details

Test Visual Aids*Rotation

Power

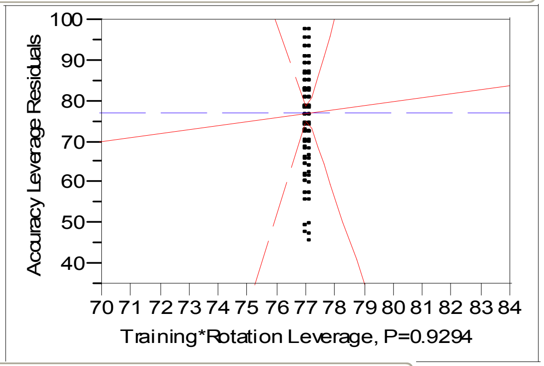
Alpha	Sigma	Delta	Number	Power
0.0500	10.12396	0.021615	192	0.0501

Least Significant Number

Alpha	Sigma	Delta	Number(LSN)
0.0500	10.12396	0.021615	842760.8

Training*Rotation

Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error
0,0	74.740208	1.4612675
0,1	70.832708	1.4612675
1,0	83.420000	1.4612675
1,1	79.253125	1.4612675

LSMeans Differences Tukey HSD

Alpha= 0.050 Q= 2.59268

LSMean[j]

LSMean[i]	Mean[i]-Mean[j] Std Err Dif Lower CL Dif Upper CL Dif	0,0	0,1	1,0	1,1
	0,0	0 0 0 0	3.9075 2.06654 -1.4504 9.26538	-8.6798 2.06654 -14.038 -3.3219	-4.5129 2.06654 -9.8708 0.84497
	0,1	-3.9075 2.06654 -9.2654 1.45038	0 0 0 0	-12.587 2.06654 -17.945 -7.2294	-8.4204 2.06654 -13.778 -3.0625
	1,0	8.67979 2.06654 3.32191 14.0377	12.5873 2.06654 7.22941 17.9452	0 0 0 0	4.16688 2.06654 -1.191 9.52476
	1,1	4.51292 2.06654 -0.845 9.8708	8.42042 2.06654 3.06253 13.7783	-4.1669 2.06654 -9.5248 1.19101	0 0 0 0

Level				Least Sq Mean
1,0	A			83.420000
1,1	A	B		79.253125
0,0		B	C	74.740208
0,1			C	70.832708

Levels not connected by same letter are significantly different

Power Details

Test Training*Rotation

Power

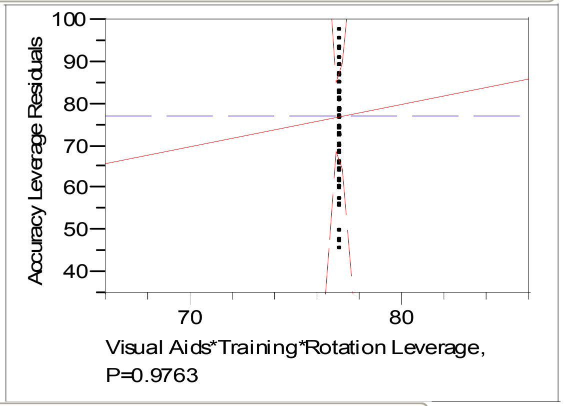
Alpha	Sigma	Delta	Number	Power
0.0500	10.12396	0.064844	192	0.0509

Least Significant Number

Alpha	Sigma	Delta	Number(LSN)
0.0500	10.12396	0.064844	93642.25

Visual Aids*Training*Rotation

Leverage Plot



Least Squares Means Table

Level	Least Sq Mean	Std Error
0,0,0	70.660417	2.0665444
0,0,1	66.666250	2.0665444
0,1,0	81.076250	2.0665444
0,1,1	76.909583	2.0665444
1,0,0	78.820000	2.0665444
1,0,1	74.999167	2.0665444
1,1,0	85.763750	2.0665444
1,1,1	81.596667	2.0665444

Power Details

Test Visual Aids*Training*Rotation

Power

Alpha	Sigma	Delta	Number	Power
0.0500	10.12396	0.021719	192	0.0501

Least Significant Number

Alpha	Sigma	Delta	Number(LSN)
0.0500	10.12396	0.021719	834696.2

VITA

The author, Sunil Addepalli was born in Hyderabad, Andhra Pradesh, India. He received the degree of Bachelor in Technology (Electronics and Instrumentation) from Jawaharlal Nehru Technological University, Hyderabad, India, in 2002 and will receive the degree of Master of Science in Industrial Engineering, in August 2005, from Louisiana State University, Baton Rouge.